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END FIELD EFFECTS IN BEND-ONLY COOLING LATTICES

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Abstract

Cooling lattices consisting only of bends (using either rotated pole faces or gradient dipoles to achieve focusing) often require large apertures and short magnets. One expects the effect of end fields to be significant in this case. In this paper we explore the effect of adding end fields to a working lattice design that originally lacked them. The paper describes the process of correcting the lattice design for the added end fields so as to maintain desirable lattice characteristics. It then compares the properties of the lattice with end fields relative to the lattice without them.

INTRODUCTION

In designing a beamline, the magnets are modeled by having a certain ideal field profile within the body of the magnet which ends abruptly when one exits the magnet. There is one exception to this, which is the a dipole magnet with a pole face that is not perpendicular to the design orbit at the entrance and/or exit to the magnet. In this case, the magnet is modeled as having a simple linear transfer matrix at each end of the magnet.

Maxwell's equations require that real magnets have fields which vary more smoothly at the entrance and exit of the magnet. The ideal field profile now smoothly changes from it's nominal value in the magnet body to zero at a point outside the "ideal" magnet body. When this is considered for dipole and quadrupole magnets, the field strengths generally must be corrected slightly to restore the expected linear behavior of the machine.

Often of greater importance are the nonlinear fields that are induced by the non-constant longitudinal profile of the desired fields. These fields cat strongly affect the chromaticity, dynamic aperture, and other characteristics of the lattice.

In this paper we look at the effect of these endfields on a ionization cooling lattice consisting solely of dipoles [1]. These lattices focus either with edge focusing or by using gradient dipoles. The goal of such a lattice is to have a low beta function (generally less than 1 m) at the absorber over very large energy acceptance (as much as a factor of 2).

TWO EXAMPLES

We describe two example lattices, and show the effect that end fields have on these lattices. The effect of end fields in all cases are estimated using COSY Infinity's [2] default fringe field model.

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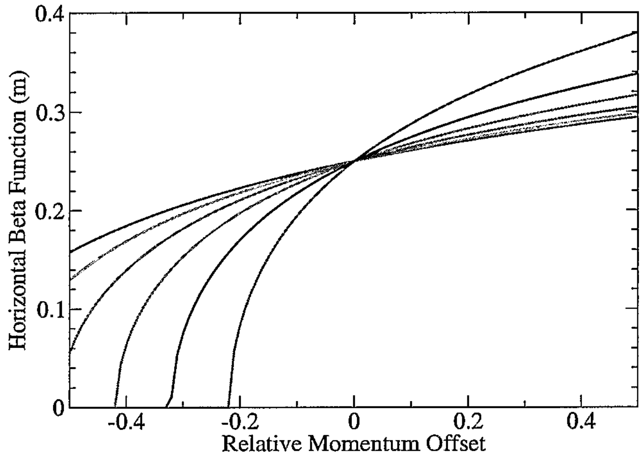

Figure 2: Horizontal beta functions for the compact edge-focused lattice as a function of the fringe field extent. The red curve (most horizontal) is for no fringe field, subsequent curves (going down on the left and up on the right) correspond to increments in the aperture (and therefore increments of the fringe field extent) of 2 cm per step, up to a maximum of 10 cm for the magenta curve.

Compact Edge-Focused Lattice

Our first example is an edge-focused lattice which is designed to have a very low beta function (25 cm) and is therefore very compact (see the top lattice in Fig. 1). Due to the fairly large initial transverse emittance in the beam, the desired magnet aperture is 21 cm. The magnet length is only 40 cm, so the fringe fields give a significant perturbation to the beam behavior. To achieve sufficient focusing, the bend angle must be fairly large: we use 90° bends.

Figure 2 shows the effect of adding the fringe fields to the magnets. As the length of the fringe fields increases (corresponding to an increasing aperture), a linear resonance at the low energy end begins to come closer to the reference energy. The magnet parameters are re-adjusted when the fringe fields are added so that the tunes and beta functions at the reference energy remain the same as they were without the fringe fields.

Figure 2 only shows the horizontal beta functions for up to a 10 cm aperture in the magnets. At 21 cm, the energy acceptance is even worse, and the beta functions get even larger, as can be seen in Fig. 3. Instead of simply trying to restore the linear parameters to their values without the fringe fields, one can instead modify the lattice to attempt to restore the lattice performance. Figure 3 also shows the results of this attempt. The beta functions have been restored to near their original values, and the energy accep-

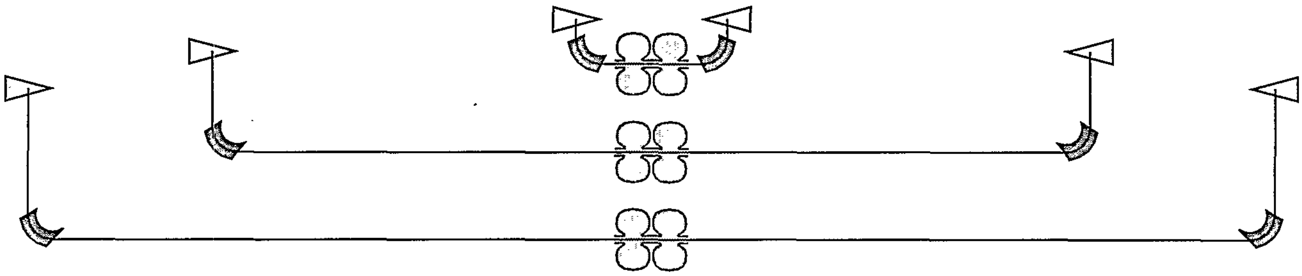

Figure 1: Compact edge-focused dipole cooling lattice. Top is the original lattice design. Below that is the lattice after adding finite-length end fields and restoring the linear behavior of the lattice. Bottom is after trying to restore the lattice performance.

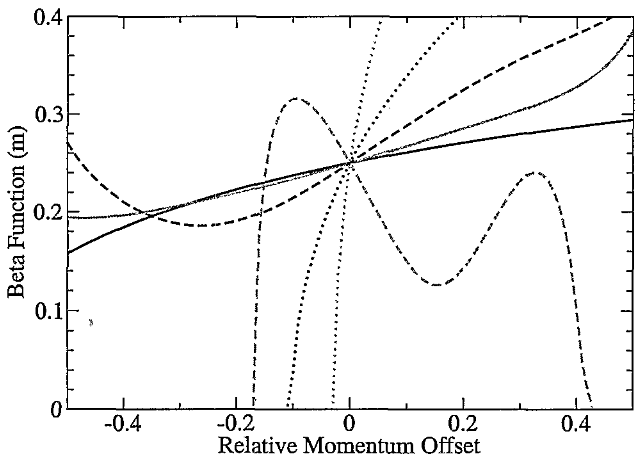

Figure 3: Horizontal and vertical beta functions at the absorber for the compact edge-focused lattice. Black lines are in the horizontal plane, grey lines are in the vertical. The solid lines are with no fringe fields, the dotted lines are with fringe fields corresponding to a 21 cm aperture, and the dashed lines are after changing the linear lattice parameters to restore good performance to the lattice.

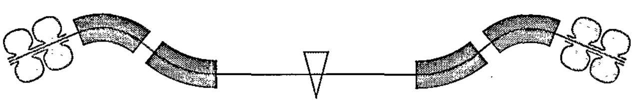

Figure 4: Layout of combined-function lattice.

tance has been improved.

Unfortunately, the modifications that were made to the lattice to compensate for the fringe field effects required a substantial lengthening of the lattice, as shown in Fig. 1. This means that the beta functions at the magnets will be substantially larger, and therefore require a larger aperture. The fringe fields will need to be lengthened further to take this into account.

Combined-Function Lattice

Figure 4 shows the layout of a combined-function cooling lattice with reverse bends to make it less compact than the previous lattice. This lattice has a larger beta function

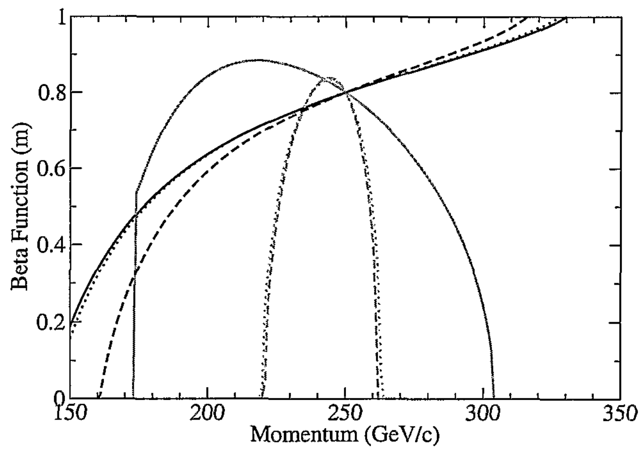

Figure 5: Beta functions at the absorber for the combined-function lattice. Black lines are in the horizontal plane, grey lines are in the vertical. The solid lines have no fringe fields, the dotted lines have fringe fields from a 1 cm aperture, and the dashed lines have fringe fields from a 10 cm aperture.

than the previous lattice: around 75 cm instead of 25 cm. The magnets are 1 m long.

Figure 5 shows the beta functions for this lattice as a function of energy for three cases: no fringe fields, very short fringe fields, and longer fringe fields. Note that even for very short fringe fields, there is a substantial effect on the vertical beta function and the energy acceptance. In fact, the effect on the vertical beta function is almost independent of the length of the fringe fields. There is a much weaker effect on the horizontal beta functions, but that effect does not appear suddenly as soon as the fringe fields are added.

This effect can be understood by considering the mechanism for linear edge focusing in a dipole. If the pole face is rotated so it is not perpendicular to the reference orbit, there is a vertical focusing force whose integral is independent of the length of the fringe field. When there is a nonzero derivative of the dispersion at the end of a bending magnet, the pole face is rotated with respect to the closed orbit off-energy. There is thus a vertical focusing which is linear

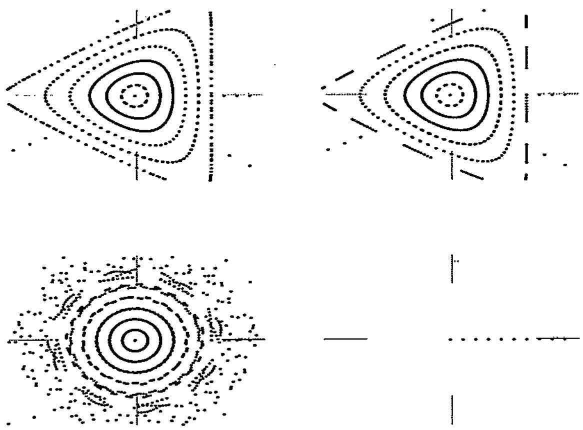

Figure 6: Tracking in the for the combined-function lattice. Top row is horizontal, bottom is vertical. Left is without fringe fields, right is with short fringe fields.

in the energy deviation, and whose integrated strength is independent of the length of the fringe fields. There is no such effect in the horizontal plane.

The relative insensitivity of this lattice to the fringe field profile as compared to the edge-focused lattice is probably related to the relatively short length of the magnets in the edge-focused case, compared to the longer magnets here. For a short magnet, the field profile is almost completely dominated by the ends, whereas for a long magnet, the ends form more of a perturbation to the field profile. The nonlinearities from the ends are also smaller relative to the integrated strength of the magnet when the magnets are longer.

Figure 6 shows the results of tracking with and without fringe fields. The vertical dynamic aperture decreases substantially when the fringe fields are added, while there is little effect in the horizontal plane.

ANALYSIS AND CONCLUSIONS

We have shown that for dipole-based cooling lattices, the magnet endfields affect the performance of the ring very strongly. One cannot design a lattice without endfields and expect it to perform even closely to it's design performance after the end fields are added. Restoring the lattice performance to it's original state often looks nearly impossible, or at the very least requires drastic changes to the lattice.

This effect is most likely so strong in cooling lattices due to the low beta functions that they require. Since the lowest order contribution from the end fields is a longitudinal field, the beam must make a large transverse angle with respect to the pole face to see a substantial effect. The low beta functions create that large transverse angle.

Endfields must be included at the very beginning of the design stage for a dipole-based cooling lattice if one expects to get even a remotely accurate picture of the performance of the lattice.

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